# DEVELOPMENT OF A CAMERA OF CALIBRATION FOR ATMOSPHERIC SAMPLING

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**Summary:**

*The increase of the pollution, in the great urban centers, it has been forcing the demand for new equipments capable to do the correct sampling of the particles in suspension in the air. These particles are of special attention, because they cause damages to our health. The smaller particles than 10µm are considered inhaled and the one of smaller size than 3µm are considered breathable, reaching the alveolar area of the lungs.*
*In the search for the decrease of the effects of the pollution, it is done necessary to monitor the physical characteristics of the aerosols (concentration and size). However the necessary procedures for the calibration of aerosol meters are badly defined, without formal instructions and documentation.*
*This article proposes to the construction of a camera of aerosol calibration that provides a calm atmosphere and controlled, with atmospheric pressure around 1 atm and speed of the air close of 0.5 m/s, for evaluation of aerosol sampling. That camera should be big enough to accommodate several instruments simultaneously, tends an area of test section relatively wide (approximately 1,0m$^2$) with a concentration of uniform and stable aerosol.*
***Key word**: calibration; aerosol; uncertainty.*

## 1. INTRODUCTION

Many of the necessary procedures for the calibration of aerosol meters are badly defined, without formal instructions and documentation. Under normal circumstances, calibrations of new instruments are made by the own manufacturers (tends to send the instrument for Europe or United States). Subsequent calibrations are accomplished when the instruments are given to the manufacturers for cleaning and repairs. Besides, a very small number of laboratories accomplish calibrations and maintenance of aerosol sampling. However, in 1993 Lewis al et, it verified that 58% of the instruments, used on that moment, they were never gaged or they were "homemade." Clearly this situation is unsatisfactory. She can drive to you differentiate considerable in the measurement of aerosol concentrations and the characterization of aerosol groups. Such inconsistencies are particularly important when the samples, removing of a work place; it is analyzed for labor effect or for environmental emission, to adapt to patterns of quality of the air. It is also important in the quality control of some industrial processes.

To rigidity, all of the instruments demand, to assure the supplied results, a calibration. Ideally, all the measures should be tracked to a primary pattern, possibly for the use of secondary patterns.

They were done, along the years, evaluations and calibrations of instruments using a variety of techniques. A technique is the introduction of the aerosol in a wind tunnel for a probe that leads him/it to the instrument. Usually the probe is of size and so that it allows a constant speed until the sampling point.

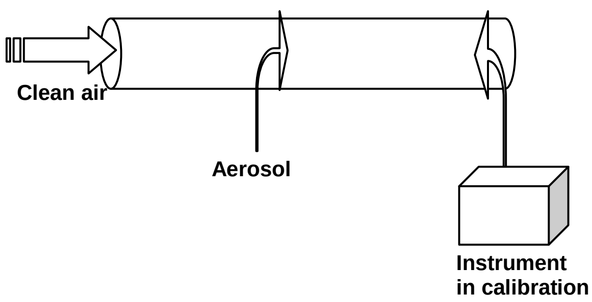


**Figure 1: Wind tunnel for calibration of atmospheric sampling. Technique 1**

Another technique is to "flood" the instrument with the aerosol so that all of the particles that enter in the healthy instrument of aerosol and not of the adjacent air. In this case, he/she is not reached to the constant speed.

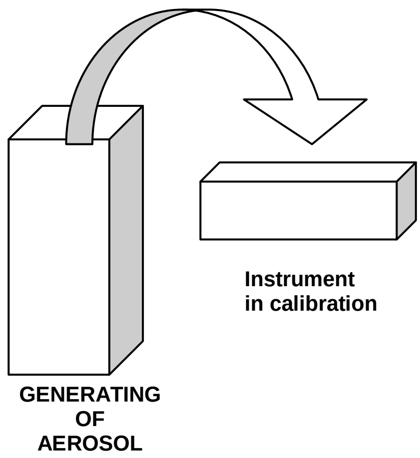


**Figure 2: Calibration of atmospheric sampling. Technique 2**

Although those techniques evaluate and they gage aerosol meters, they request probes until the entrance of the instrument. In some cases those techniques can be desirable for calibration. However, in other cases, as in a program of instrument evaluation, it can be more desirable to expose the whole instrument to a calm atmosphere that contains the aerosol. This way, the presence of sources of heat of the own instrument, in his/her global sampling of the particles of the aerosol, it will be included in the calibration. The conditions during the calibration are as if the instrument was being used in calm air.

This article proposes a project of construction of a camera of aerosol calibration that provides a calm atmosphere and controlled (pressure adapts around 1 atm and speed of the air in 0.5 m/s) for evaluation of aerosol sampling. That camera should be big enough to accommodate several instruments, tends an area of test section relatively wide (approximately 1.0m$^2$) with a concentration of uniform and stable aerosol.

Like this, we can gage the atmospheric sampling in close conditions to the use, and this way, to validate the characteristics metrological of the instrument, basically, his/her measurement uncertainty and his/her systematic mistake.

## 2. CAMERA OF CALIBRATION

2.1. Physical characteristics

Conventions were established for measure of airborne powder concentrations in the work place (Griffiths; attn a1 998). Those conventions based on the efficiency of aspiration of mannequins tested in tunnels of wind of speeds among (1.0 to 4.0) m/s. The same conventions that describe the dependent penetration properties of the size of the aerosol particles in the human breathing system were published by the American Conference of Industrial (1997) Hygienists, International Organization for Standardization (1983), and the European Committee for Standardization (1992). In 1998, Baldwin and Maynard they accomplished studies and they found, in the work place, wind that you/they rarely exceed 20 cm/s. Although many work places possess wind speeds below 20 cm/s, the workers' movement makes possible a higher effective wind speed in the samples. In spite of, there are a lot of situations where the worker is in rest and a criterion of low movement of air is applied. Aitken et al. (1999) it showed that in atmospheres of low movement of air, the aspiration efficiency is larger than the conventional. Sampling tested in that atmosphere of low movement of air showed larger aspiration efficiency than in previous tests of wind tunnel, the external wind speed of 0.5 m/s.

Those results suggest that more studies should be accomplished to collect information on the sampling efficiency, as well as the respirability curve, in an atmosphere of movement of speed of the low air that he/she resembles each other to the conditions in the work place in closed enclosure.

Traditionally, that study type requests a calibration camera with a generation system in the top and located sampling in the bottom (Marple and Rubow 1983; Chen et all. 1999; Kenny et all. 1999; Koch et all. 1999).

A schematic diagram of the camera of test of proposed aerosol is presented in Fig 3. The camera will have 2.0m of height and a square section of 1.0m$^2$ of side approximately. Aerosols monodisperse and polydisperse will be generated in the top of the camera, being diluted by clean (filtrate) air. The aerosols will be completely mixed in the segment 1 of the camera (to see fig. 1) for the energy of the jet of the aerosol (turbulent drainage). That section guarantees the uniformity of the aerosol, they put with high-speed and turbulence. Below this section a structure exists in thick

"beehive" where the turbulence of the air will be reduced, producing a low speed, reaching the second segment. A drained rotative table will allow a flow of air on her, forming the base of the test section. The table is made so that it can be rotated, promoting a continuous movement of the instruments, about the test section, in order to reduce the effects that any variation in aerosol concentration inside of the test section. Under the rotative table a filter will be put HEPA where the particles will be filtered of the draft. The air is sucked of the camera by a fan.
Along the camera points of collection of temperature data are put, pressure inside the camera and speed of the drainage, similar of guaranteeing uniformity of those parameters.

Two on the four sides of the camera will be projected as workstations and each side is equipped with a window of approximately (50 x 70) cm and a pair of door-gloves. Like this, during a test, up to two people, one in each window, he/she can work the instrumentation inside of the camera.

The windows can be removed for the placement of the sampling. Besides, the camera is cut horizontally between the windows and the door-gloves. Like this, for the installation of the very big sampling, or for the establishment of the table inside of the camera, the superior portion of the camera should be removed. In the part of bass of the camera, he/she is located the electric facilities and the lines of air of the sampling for the exterior of the camera.

The rotative table possesses variable speeds through a reversible electric motor. The motor should be located out of the camera. An electric motor inside of the camera it would act as a source of heat, capable to create convection currents. The direction of rotation of the table can be inverted, avoiding, like this, that the lines of air and thread tramways are rolled up around of the table. With this arrangement, the table cannot rotate more than $360^0$.

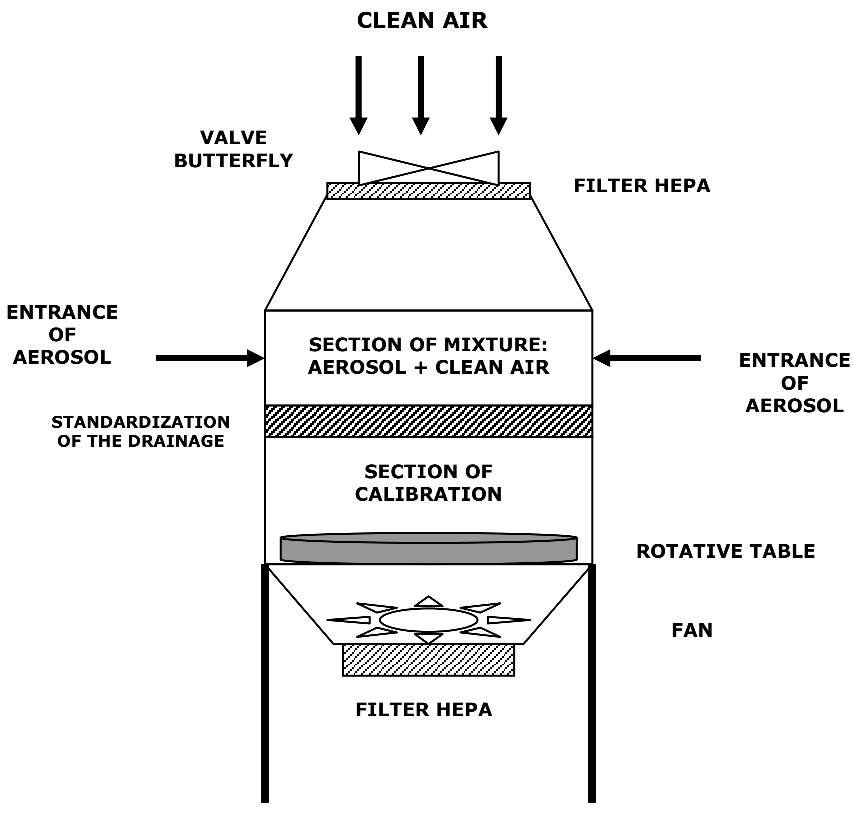


**Figure. 3: Model of camera of calibration of proposed aerosol**

2.2. Techniques of Measurement: Appraised parameters.

a) Size of the particles

The size of the particle is his/her more important parameter. He defines the physical characteristics of the airborne particles. The distribution of size of an aerosol group is usually polydisperse, sometimes even with 100 times the reach among the smaller and larger (Hinds - 1982) particles. An evaluation of as the aerosol properties it can vary with the size of the particles is fundamental to his/her understanding. It is necessary to consider aerosol properties to his/her group, applying them in terms of properties of individual size.

Aerosol particles usually possess a characteristic dimension, or more frequently a compatible equivalent diameter to the of a spherical particle. These dimensions are expressed in micrometers.

Aerosols can vary among 0.001μm to 100μm of diameters. Powder particles and pollen are usually larger than 1μm, particles of smoke are smaller.

In general, the equivalent diameter is defined as the diameter of the spherical particle that he/she has the same characteristic behavioral of the no-spherical particle, under the same conditions. Very frequently this physical property refers to a parameter that describes the aerodynamic behavior of the particle.

The aerodynamic ($d_{ae}$) diameter is of fundamental importance. It allows an understanding of the behavior of the airborne particles, and it is defined as the diameter of the sphere of unitary density that he/she has the same adjustment speed, under gravitational forces, that the particle.

b) Selection of Equipment - Materials of Reference and Uncertainty of Measurement

Necessary and careful considerations should be taken before executing any measurement of the properties of the aerosols. If the obtained data of the measurement are not satisfactory for the intended application, the measurements should be discarded. For instance, if the user is interested in the deposition of an aerosol group in the lung, it is senseless to examine the aerosol particles under a microscope to determine the size distribution based on an equivalent geometric diameter. The measurement can be exact and necessary, but it won't be pertinent to the purpose, as the deposition of the particles inside of the lung will depend on his/her aerodynamic diameter and not of his/her equivalent geometric diameter, we will measure a wrong parameter well.

Like this, great care should be had in the choice of the measurement technique.

All measurement has an associated uncertainty that should be quantified, for the measurement to have reliability metrological. The following points should be considered taking into account the measurement uncertainty:

- The expanded uncertainty should include an estimate of the uncertainties originating from of the influence variables properly identified and described through methods and procedures.
- All of the relative uncertainties to the measurement process should be taken into account, besides the uncertainties attributed to the measurement equipment, patterns of reference (besides material used as a reference pattern) measure, operators, measure procedures and environmental conditions.
- For the calculation of the uncertainty of the calibration process, the cumulative effect of each successive phase of the calibration procedure should be evaluated.

c) Statistical

The two parameters of larger importance in the calibration of aerosol analyzers are the particle concentration and the size distribution.

The measurement of the size and concentration of particles done with aerosol analyzers depend on the instrument that is operated. Although the behavior of the particle can be described in many aerosol sampling, is necessary to check the operational characteristics of the sampler (tendency and measurement uncertainty, for instance) with particles pattern to verify if they are operating inside of per-established criteria. This concern is especially true when the measures have to satisfy patterns of quality warranty (for instance: ABNT ISO 9001: 2000) or legal demands.

Aerosol analyzers need to be gaged by four reasons:

1. To assure that the instrument is working correctly (warranty of routine quality).
2. To compare acting with theoretical predictions and with other analyzer of the same type.
3. To determine the measurement uncertainty, as well as to correct concentration values and medium diameter of particles.
4. To compare measures of a certain aerosol with other instruments that work with different beginnings.

The final comparison is of fundamental importance when we accomplished different measurements of an unknown aerosol. The geometric diameters of a lot of particles can be quite different from their aerodynamic diameters.

All of the properties of healthy transport of aerosols strongly dependent of the size of the particle, and the establishment of these relationships are the main objective of many studies that you/they involve aerosol analyzers. Most of the environmental aerosols are polydisperse, and it is necessary to assume that the properties of an aerosol polydisperse, with a medium particle diameter, coincide with the properties corresponding of an aerosol monodisperse, with the same diameter. Although there was a tendency to use aerosols monodisperse in the calibrations, it was recognized that calibration that you/they use aerosol polydisperse, very defined, can be a valuable exercise, particularly if the sensibility of the instrument be affected by a property that depends on the size of the aerosol, as refractive index.

The distributions of size of the particles of many aerosols approximate of a distribution lognormal (fig. 4) and the dispersion degree can be characterized by the geometric standard deviation (Eq.1):

$$\ln(\sigma_g) = \left[ \frac{\sum_i^N \ln\left(\frac{d_i}{\bar{d}_g}\right)^2}{N} \right]^{1/2} \quad (1)$$

Where, N is the number of particles of the sample with diameter $d_i$, and it is the medium geometric diameter given for:

$$\bar{d}_g = \left[ \prod_i^N d_i \right]^{1/N} \quad (2)$$

For most of the practical purposes an aerosol monodisperse is considered if .g goes smaller than 1.2 and many generators are capable to produce aerosols with smaller than 1.1.

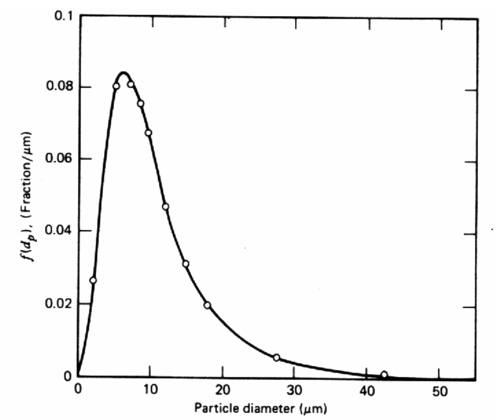


**Figure. 4: Lognormal distribution (ref. Aerosol Technology)**

**3. I SCORE TO BE GAGED: IMPACTORS IN CASCADE.**

3.1. Inertial Impactors

Impactor is a special case of curvilinear movement that possesses extensive application in the sampling and measurement of aerosol particles. Because of his/her importance, the impactor was analyzed, theoretically and experimentally, more completely than any other process of aerosol separation. In the first half of the century XX, the impaction was a common method to collect dust for the evaluation of professional atmospheres. Since 1960, impactors in cascade were used extensively for the measure of distributions of particle size by mass.

All of the inertial impactors work for the same beginning. As shown in Fig. 5 the aerosol is gone by a mouthpiece and the exit (jet) flow drove her against a plate. The plane plate calls him self impaction plate, and it provokes an abrupt inclination in the flow of $90^0$. Particles whose inertia exceeds certain value are unable to accompany the flow and it collides (impacts) with the plate. Like this, an impactor separates aerosol particles in two size strips; larger particles than in certain aerodynamic size they are moved away of the draft, and smaller particles than it stays in the air and they cross the impactor.

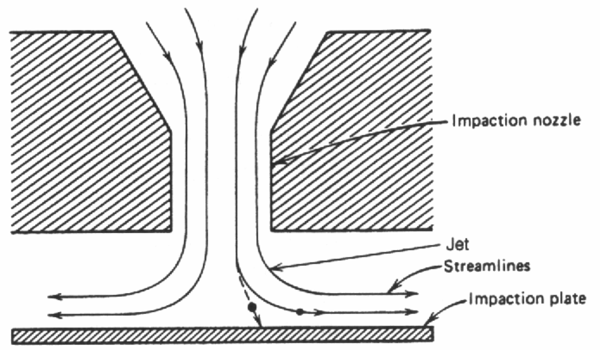

**Figure. 5 Section of an inertial impactor (ref. Aerosol Technology)**

The theory of impactors looks for to explain the form of the curve of efficiency collection against the size of the particle (sees Fig. 6). The parameter that governs the collection efficiency is a characteristic diameter, adopted here as the aerodynamic diameter.

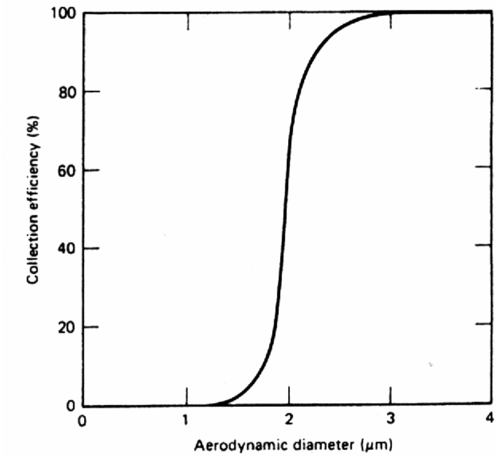

**Figure. 6. Typical curve of impactor efficiency (ref. Aerosol Technology)**

Inertial impactors measure the aerodynamic characteristics of an aerosol group in the place of the physical characteristics, and then it is fundamental use aerosols gaged that possesses much known aerodynamic properties.

The impactor selects the particles for his/her size in each apprenticeship, discreetly. The objective of his/her calibration is to determine the aerodynamic diameters in that each apprenticeship selects particles with an efficiency of 50% (d50). The calibration methodology includes the following steps:

a) Selection of the calibration particles,
b) Generation and characterization of the calibration aerosol,
c) I rehearse of the aerosol in calibration,
d) Quantitative measurement of the selected material,
e) Analysis of data.

3.2. Impactors in cascade

We can operate several impactors simultaneously with sizes of different cut. The use of several impactors in parallel is not common, because of the complexity of controlling multiple flow taxes. The most common approach to operate several impactors in series, organized first in order of size of decreasing cut is called of impactor in cascade. Each separate impactor is called an impaction phase.

Each phase is provided with a plate of removable impaction for determination gravimetrical (or chemical substance) of the collected particles. The last phase in a cascade impactor is usually followed by a filter that captures all of the smaller particles than the size of cut of that phase.

The aerosol flows in sequence for successive phases, the particles captured in the plate of impaction of a certain phase represent all of the smaller particles than the size of cut of the previous and larger phase than the size of cut of the phase in subject. A phase of the impactor consists of a mouthpiece section and the impaction plate, in that their jets veneer how shown in Fig.7.

Of the measures gravimetrical of each phase, it can be certain the fraction of the total mass in each strip of aerodynamic size.

We assumed that the particles adhere to the impaction surface if they hit the plate. For liquid particles, this is almost always correct. Solid particles, however, they can jump when hit in the impaction plate or to adhere and later to jump outside of the plate. The effect is the same.

Once a particle jumps, it is probable that continues to jump in subsequent phases, because the impaction speed is larger in these phases. Covering the impaction plate with a fine film of oil or grease reduces the incidence of jumps.

Particles can be deposited in the passages among phases of a cascade impactor. Such deposition is called loss among apprenticeships and it represents other operation problem in the cascade impactors. For impactors of conventional cascade, losses among apprenticeships are it mainly problem of big particles that are lost in the first two phases. Particles get lost through the inertial removal to you curve in the path of the flow. Since these losses among apprenticeships depend on the size of the particle and they are not included in the collected mass, they distort the size distribution for smaller sizes. Losses among apprenticeships can be reduced projecting the impactor to minimize curves among apprenticeships in the first phases or operating the impactor to a tax more flow drop.

It is recommended that the calibration of the impactor of cascades is executed with the complete device, in other words, with all of the united apprenticeships.

Although many users trust the calibration curves supplied by the manufacturer, this practice should be avoided because the respective curves are generated by lots, hurting like this an I begin fundamental of the calibration: every equipment should be gaged individually, same because secondary changes in the geometry can have an effect in the characteristics of acting of the impactor, especially for impactors of multiple hole.

In the experiment proposed in this work, we will use the impactor in cascade of three and of eight apprenticeships (Fig. 8) developed by the Prof. Marcos Sebastião de Paula Gomes, of the department of mechanical engineering of PUC-Rio.

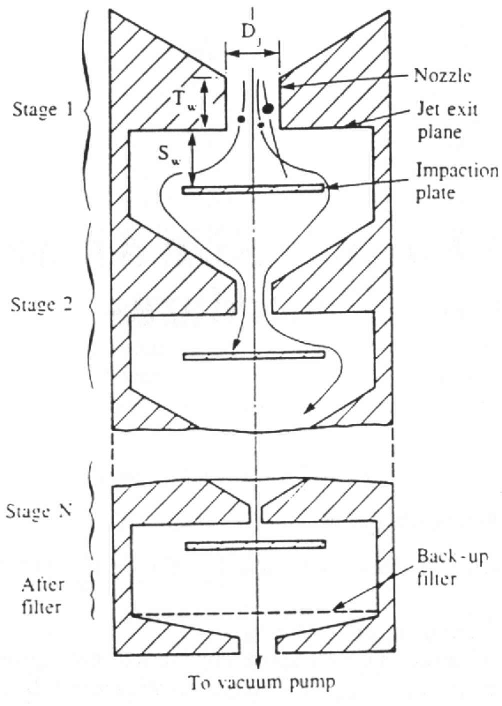


**Figure. 7: Beginning of the cascade impactor (ref. Aerosol Technology)**

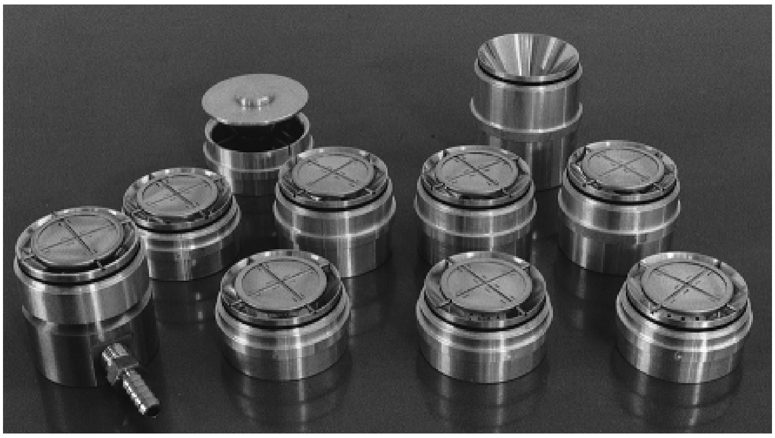

**Figure. 8: Apprenticeships of Impactador in cascade developed by the Prof. Marcos S. P. Gomes.  DEM/PUC-Rio**

(a) Selection of Particles of Calibration

Calibrations can be executed using particles monodisperse or polydisperse. The advantage of particles monodisperse is that the test particles are defined in terms of the size, it forms, density and optical properties. Although several experiences should be executed to cover the operational reach of the device, these tests can be minimized by careful selection of the size of particles.

The advantage of the use of particles polydisperse is that the impactor is gaged completely in a single experiment; although the analysis of data is more complex than with particles monodisperse and the final uncertainty is a little larger.

Calibrations that use particles monodisperse are recommended due to larger accuracy and precision.

(b) Generation and Characterization of Aerosol of Calibration.

Particles should be characterized produced by the aerosol generator. It is fundamental the measurement of the diameter of the particles generated simultaneously with the collection done by the impactor of cascades, using a diameter meter and concentration pattern.  The particles should be classified (diameter and concentration) in the moment of the calibration.

The flow to which the calibration aerosol is tested should be measured. The choice of the flow depends on the application of the device in calibration, and it can differ of instrument for instrument. The influence should be verified in the change of the aerosol flow and the impact that that would provoke in the calibration. The temperature of the aerosol, it should be registered, as well as his/her relative humidity and pressure adapts.

(c) Measurement in each apprenticeship. Analysis of Data

The object of a calibration is to characterize the size strip inside of which the efficiency of the inertial sifter varies from 0 to 100%. An ideal sifter would have only step of 0 for 100% of efficiency, and the particle classified according to the size in that it happened that efficiency, they define the acting of the impactor. However, this behavior is never observed in practice because of irregularities in the paths of the particles, particle jump and return that result in efficiency curves against such of particle denominated curve characteristic of the impactor.

Many technicians prefer to gage aerosol analyzers with particles monodisperse, in spite of the requested effort. Analysis of data and interpretation is much easier when particles monodisperse of spherical format are used, since the sizes of the aerodynamic particles are much defined and orientation effects don't happen. Particles solid and liquid monodisperse are used in the calibrations of the aerosol analyzers; particle jump is more probable to happen when solid particles are used (Franzen and Fissan (1979)), while liquid drops can break in the impact with the collection plates. The indication is to gage with solid particles if the classifier be used to analyze solid particles and with liquid particles when it is liquid.

In this work, we will use particles of latex well-characterized. The procedure is repeated for different particle sizes to that the curve of collection efficiency is made. The size that corresponds her/it an efficiency of collection of 50% defines the acting of the classifier and it is called of effective (ECD) expansion diameter. If N' and N are the concentrations of particles before and then, respectively, of passing for the analyzer, the efficiency of collection of a single phase for particles of size d1 is determined for:

$$\xi(d_1) = \left[1 - \frac{N}{N'}\right] \quad (3)$$

This efficiency is plotted in a graph against aerodynamic diameter to produce a curve of collection efficiency for each apprenticeship. A mathematical function is provided to the data, and the aerodynamic diameter that corresponds her/it an efficiency of collection of 50% (d50) is certain for each apprenticeship (see fig. 9).

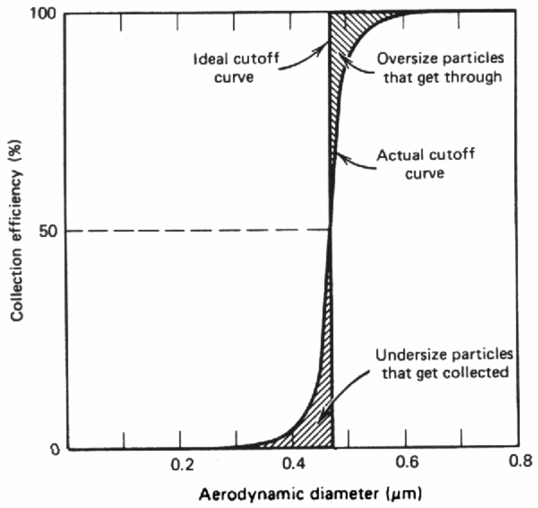


**Figure. 9 Curves of efficiency of real and ideal impactor. (ref. Aerosol Technology)**

## 4. CONCLUSION

The choice of a method of private calibration depends in a large part of the type of particle analyzer that is gaged and the degree of accuracy requested. For so much it is necessary to build an atmosphere (calibration camera) that can reproduce, the closest possible, the environmental conditions in that this aerosol sampler will find. This article of the emphasis in the calibration procedures and some cares in the construction of the calibration camera. Pointing out the aerodynamic diameter and the distribution of size of corresponding particle, as well as his/her concentration.

Careful should be been to reach the great conditions in the generation and sample of the aerosol in test. Calibrations that use particles monodisperse are more frequently accomplished in relationship the ones that use aerosols polydisperse, in spite of the involved extra work, the uncertainties introduced by the technique monodisperse are smaller. That is particularly truth with impactors and they are certain for curves of collection efficiency that are functions usually sensitive of the particle size.

Other physical properties of the calibration are frequently as significant as the monodispersed degree. For instance, the uniformity in the drainage, in what concerns the temperature, pressure and concentration, in the section of calibration of the camera, the choice of particles solid or liquid, the standard meter of concentration and distribution of used (in this work we used APS 3320) size. Particle density, porosity and it forms also have an influence marked in the sensibility of analyzers of size of aerodynamic particle.

It is recommended that all analyzing of aerosol it is gaged regularly, as maintenance politics.

The acting of auxiliary equipment as meters of flow of gas, pressure gauges, etc., it is important, and these systems need to be gaged regularly before the use.

The main contribution of this work is to call the attention for the need of gagging, with reliability metrology, particulates sampling and with that to create methodologies and patterns for that end.

The camera of presented calibration is in construction phase and soon we can present experimental results.

## 5. REFERENCES


A. Fuchs (1978), **'Aerosol Impactors (A Review)'**, Chapter 1 in **'Fundamentals of Aerosol Science'**, Ed.: D. T. Shaw, John Wiley and Sons, New York, USA.

C. Hinds (1982), **'Aerosol Technology**: Properties, Behavior and Measurement of Airborne Particles', John Wiley and Sons, New York, USA.

D. Boulaud, M. Diouri and G. Madelaine (1981), **'Parameters Influencing the Collection Efficiency of Solid Aerosols in Cascade Impactors',** p.125 in Proc. 9th Conf. European Association for Aerosol Research, Duisburg, Germany.

D. Horton, R. D. Miller and 3. P. Mitchell (1991), **'Characterization of a Condensation-Type Monodisperse Aerosol Generator (MAGE)'**, J. *Aerosol Sci.*, 22(3), 347.

Dennis (1976), **'Handbook on Aerosols'**, Technical Information Center, US Energy Research and Development Administration, USA.

Franzen and H. 3. Fissan (1979), **'Collection Behaviour of Andersen Non-Viable Samplers and Andersen Stack Samplers Using Glass Fibre Collection Plates'**, *StaubReinhalt. der Luft*, 39, *50.*

Gomes, Marcos S.P. **Design of an eight-stages cascade impactor for the classification of airborne particles.** COBEM.1997.

Griffiths, W.D; Mark. D; Marshall. I. A and Nichols, A. L, (1998), '**Aerosol Particles Size Analysis – Good Calibration Practices',** AEA Technology.

H. Vincent (1989), **'Aerosol Sampling: Science and Practice'**, John Wiley and Sons, Chichester, UK.

J. Fissan and C. Helsper (1982), **'Techniques for Calibration of Dust Measurement Methods'**, VDI Berichte No.429, Germany.

Lippmann (1989), **'Calibration of Air Sampling Instruments'**, p.73 in 'Air Sampling Instruments for Evaluation of Atmospheric Contaminants', 7th Edn, Ed.: S. V. Hering, Am. Conf. Govern. Indust. Hygienists, Cincinnati, Ohio, USA.

Marpel, Virgil A and Rubow, Kenneth L, (1983), **'An Aerosol Chamber for Instrument Evaluation and Calibration'**, Am Ind Hyg. Assoc. J 44(5): 361-367.

N.J. Lewis, P. Mitchell, W. D. Griffiths, D. Mark and R. S. Sokhi (1993), **Survey of User Needs, National Measurement Infrastructure for Aerosols and Particulates in the Gas Phase/VAM**, AEA Technology Report AEA-EE-0442.

P.A. Baron (1986), **'Calibration and Use of the Aerodynamic Particle Sizer (APS 3300)'**, *Aerosol Sci. Technol.*, 5(1), 55.

T.Allen (1981), **'Particle Size Measurement'**, 3rd Edn, Chapman and Hall, London, UK.

Y. H. Liu (1976), **'Standardization and Calibration of Aerosol Instruments', p.39 in 'Fine Particles'**, Ed.: B. Y. H. Liu, Academic Press, New York, USA.